Quantifying the Amplitude, Structure and Influence of Model Error during Ocean Analysis and Forecast Cycles

Andrew M. Moore
Department of Ocean Sciences, 1156 High St.
University of California
Santa Cruz CA 95064
Phone: (831) 459-4632 fax: (831) 459-4882 email: ammoore@ucsc.edu

Chris Edwards
Department of Ocean Sciences, 1156 High St.
University of California
Santa Cruz CA 95064
Phone: (831) 459-46323734 fax: (831) 459-4882 email: cedwards@ucsc.edu

Ralph F. Milliff
Colorado Research Associates
3380 Mitchell Lane
Boulder CO 80301
Phone: (303)-415-9701 fax: 720-836-5609 email: milliff@cora.nwra.com

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LONG-TERM GOALS

The long-term scientific goals of this research project are to:

1. Understand and quantify the sources of error in ocean models that fundamentally limit the practical predictability of the coastal ocean circulation.
2. Use information about model error to improve ocean circulation estimates obtained using weak constraint data assimilation methods.

OBJECTIVES

The primary objective of the proposed research is to develop a weak constraint, 4-dimensional variational (4D-Var) data assimilation capability for the Regional Ocean Modeling System (ROMS) with application to the California Current System (CCS). The CCS is of considerable socio-economic and strategic significance to the United States, and ROMS CCS is transitioning towards a real-time forecasting system in support of the U.S. west coast components of the Integrated Ocean Observing System (IOOS). This project is therefore very timely given the limiting nature of model errors on coastal ocean prediction.

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APPROACH

The proposed research activities seek to quantify the amplitude, structure and influence of model error in ocean analysis and forecast systems using two approaches. The first will use the ROMS 4D-Var data assimilation systems (Moore et al, 2010a,b,c) in combination with Bayesian hierarchical modeling to identify sources of model error and their characteristics**.** The second approach will use Generalized Stability Analysis (GSA) to explore the fastest growing model error structures, how these relate to different ocean circulation regimes, and the implied bounds on model error growth and predictability.

As noted in the original proposal, the project will involve three major research tasks:

Proposed Research Task #1:
(i) A sequence of strong constraint 4D-Var experiments for ROMS CCS will be performed for the period 2000-present. (ii) A surface flux BHM will be used to identify periods when model error is a significant factor. The basis for the CCS BHM will be the BHM of Milliff et al (2009) for the Mediterranean surface winds which will be reconfigured for the ROMS CCS domain and expanded to include surface fluxes of heat and momentum. The BHM data stage will use QuikSCAT surface vector winds, and COAMPS surface winds and fluxes, while the process model stage will utilize the bulk surface flux model subcomponent of ROMS and COAMPS standard 10 m atmospheric boundary layer variables. (iii) A second sequence of weak constraint 4D-Var experiments will then be performed using the surface flux BHM and strong constraint flux increments to inform the model error *prior* and so build and test various different hypotheses about model error. (iv) A detailed analysis of the spatio-temporal corrections for model error from each weak constraint 4D-Var assimilation cycle will be performed to identify the nature of the model errors.

Proposed Research Task #2:
A complete characterization of model error during each 4D-Var cycle is provided by the *posterior* covariance. ROMS 4D-Var permits computation of the leading eigenvectors (EOFs) of the *posterior* error covariance matrix. Spatio-temporal variations in the structures of the leading EOFs of *posterior error* will yield *posterior* information about the efficacy of the resulting 4D-Var circulation estimates. Therefore a detailed analysis of the leading EOFs of the *posterior* model error covariance matrix will also be performed for the assimilation sequences performed during Task #1(i) for strong constraint and Task #1(iii) for weak constraint.

Proposed Research Task #3:
(i) The stochastic optimals (SOs) and forcing singular vectors (FSVs) of any time evolving circulation can be computed using the ROMS GSA took-kit described by Moore et al (2004). A systematic study of the FSVs and SOs associated with model error will be performed for ROMS CCS using hindcasts for the period 2000-present. Hindcast initial conditions will be generated using weak constraint 4D-Var during Task 2. Since the leading FSVs and SOs are the most damaging model errors for the hindcast interval, they will yield upper bounds on model error growth, and the loss of predictability of the circulation during each hindcast interval due to the growth of model error. (ii) The projection of the *posterior* model errors diagnosed from the weak constraint 4D-Var experiments of Task #1 onto the FSVs and SOs will also be examined

WORK COMPLETED

Funding for this project arrived late in the fiscal year, so the search for critical research personnel could not begin until the Spring. However, we have now hired a new post-doctoral research fellow, Dr. Polly Smith, and a new graduate research associate, Kevin Smith, to work on this project. Polly recently obtained her PhD in Applied Mathematics at the University of Reading in the U.K. The topic of her research was variational methods for data assimilation and parameter estimation, so she is eminently qualified for this project. Kevin is a Physics graduate from UC San Diego, and has also worked for an ocean forecasting company based in San Diego. His strong background in physics, mathematics and operational ocean forecasting make him an ideal candidate for this project also. Kevin is a new graduate student in the Ocean Science Dept at UC Santa Cruz, and started here on 23 Sept. Polly will begin work on 4 Oct.

RESULTS

As mentioned above, key research personnel for this project have only just been hired, so progress on this project and has been understandably limited. However, a major activity of relevance to this award was a ROMS 4D-Var Workshop held at UC Santa Cruz, 12-16 July, 2010. The workshop was designed for expert ROMS users with the aim of teaching them how to configure and run the extensive suite of ROMS 4D-Var systems and tools. The workshop was attended by 37 scientists and students from seven different countries. Polly Smith and Kevin Smith also attended the workshop, and this was an important part of their initial ROMS training. The project Co-PIs also attended and participated in the workshop, which also provided a valuable forum for focusing project ideas.

The workshop was comprised of a series of formal lectures, informal tutorials, and hands-on exercises built around ROMS configured for the California Current System. Lecture notes are available at http://myroms.org/index.php?page=4DVAR_2010_agenda, while https://www.myroms.org/wiki/index.php/4DVar_Tutorial_Introduction provides detailed information about the hands-on exercises.

Now that the project team is in place, a project kick-off meeting involving all project personnel is planned for Fall, 2010.

IMPACT/APPLICATIONS

This project contributes significantly to the functionality and utility of ROMS, a popular and important community model and resource. ROMS is unique in that of all the community ocean models that are available, it is the only model that possesses such a wide range of 4D-Var algorithms, analysis tools, and diagnostic capabilities.

TRANSITIONS

The new ROMS utilities developed as part of this project will be freely available from the ROMS web site http://myroms.org and will be actively used and further developed by other research groups in the U.S. and elsewhere as user competence increases.

RELATED PROJECTS

The work described here is closely related to the following ONR supported projects:

“A community Terrain-Following Ocean Model (ROMS)”, PI Hernan Arango, grant number N00014-08-1-0542.

“Bayesian Hierarchical Models to Augment the Mediterranean Forecast System”, PI Ralph Miliff, grant number N00014-05-C-0198.

“Understanding Predictability of the Ocean”, PI Brian Powell, grant number N00014-09-1-0939.

“Bayesian Hierarchical Model Characterization of Model Error in Ocean Data Assimilation and Forecasts”, PI Ralph Milliff, grant number N00014-10-C-0354.

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PUBLICATIONS

None as yet.